Relative Timing of Neutrinos from the Fermilab Debuncher and the MiniBooNE Beam

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It may be interesting to use the MiniBooNE detector to detect neutrinos from muons decaying in the Debuncher, which is used as the first stage of stochastic cooling in the Antiproton Source. If so, it is useful to know the time during which the Debuncher neutrinos traverse the MiniBooNE detector relative to the time during which neutrinos from the MiniBooNE beam traverse it.

Starting Times for Debuncher and MiniBooNE Neutrinos

Four assumptions will help to define a clear answer to the times after which neutrinos start to arrive at the MiniBooNE detector. The assumptions are:

1) MiniBooNE will limit its operation to a maximum of 5 Hz.
2) The train of MiniBooNE beam pulses will be contiguous.
3) From the Booster's point of view, the first Booster pulse of the pulse train destined for MiniBooNE will directly follow the last Booster pulse destined for the Main Injector.
4) The time for the Main Injector acceleration ramp and other beam manipulation is no shorter than today.

Figure 1 shows the situation in April 2003 when MiniBooNE is running and the Main Injector is sending beam to the Antiproton Source for stacking. One Booster pulse is transferred to the Main Injector, and it is followed immediately by seven Booster pulses which are sent to MiniBooNE. This pattern is in conformance with Assumptions #2 and #3.

Figure 2 shows the situation in April 2003 when MiniBooNE is running and the Main Injector is not sending beam to the Antiproton Source for stacking. There are ten Booster pulses, all of which are sent to MiniBooNE. If the Main Injector cycle time were 2 seconds, this would correspond to a 5 Hz rate for MiniBooNE in accordance with Assumption #1. Today however, this is not the case; the Main Injector cycle time is greater than 2 seconds, and typically the MiniBooNE rate is closer to 3 to 3.5 Hz.

We now expand the time scales to determine how long the beam is in the Main Injector; we'll use this to derive the time difference between Debuncher neutrinos and neutrinos from a MiniBooNE beam pulse. Figures 3a and 3b show the regions near the injection and extraction times in the Main Injector on an expanded scale. From Figure 3a the injection time into the Booster appears to be about 19 msec and the injection time into the Main Injector appears to be about 53 msec. This difference is 34 msec. The time the beam is in the Booster is very close to one half of 1/15 of a second, or 33.3 msec. Thus using these figures to determine times is good to about a millisecond or so.

From Figure 3b the extraction time from the Main Injector appears to be about 839 msec. This corresponds to the time that the protons are sent to the Antiproton Target; shortly thereafter muons will arrive in the Debuncher and neutrinos will begin to arrive at the MiniBooNE detector. Thus, the time the beam is in the Main Injector is about (839 - 53) = 786 msec.

If Assumption #3 is true, the extraction of the first MiniBooNE pulse occurs 66.7 msec after the beam is injected into the Main Injector. And the tenth MiniBooNE pulse would occur 667 msec after beam is injected into the Main Injector.

If Assumption #4 also holds, then the tenth beam pulse leaves the Booster for MiniBooNE about (786 – 667) = 119 msec before the beam leaves the Main Injector destined for the Antiproton Source. One can also calculate that an 11^{th} MiniBooNE pulse would arrive (119 – 67) = 52 msec before the beam leaves the Main Injector.

The times given above are the times protons leave the Main Injector or the Booster. There are additional delays, which are not explored in detail in this note. On the one hand, the protons from the Main Injector go along a beam line to the Antiproton Target, and then negative particles go along another beam line to the Debuncher, and some of the neutrinos created in the Debuncher then go to the MiniBooNE detector. On the other hand, protons from the Booster go along a beam line to the MiniBooNE target in which particles are created some of which decay to neutrinos, which then go to the MiniBooNE detector. These additional flight times are associated with distances of order one kilometer. Since the particles are going at nearly the speed of light, these flight times are less than about 3 microseconds, which are tiny compared to the 119 msec given at the end of the previous paragraph.

Nevertheless: Given the four assumptions, the starting time for neutrinos passing through the MiniBooNE detector from the tenth MiniBooNE beam pulse is much earlier (more than 0.1 second) than the starting time for neutrinos from the Debuncher.

Time Distributions of Debuncher and MiniBooNE Neutrinos

The time distribution of neutrinos passing through the MiniBooNE detector from the MiniBooNE beam and from the Debuncher are very different. On the one hand, the neutrinos from a single pulse of the MiniBooNE beam are confined to about 1.6 microseconds, and the distribution within this time is primarily determined by the distribution of a single batch of 8 GeV kinetic energy protons from the Booster, which are arranged in nearly equal intensity bunches spaced apart by about 18.8 nsec. On the other hand, the neutrinos from the Debuncher are the result of muons, which decay as they circulate over and over again around the Debuncher, taking about 1.6 microseconds per pass. Assuming the Debuncher muons have a momentum of 8 GeV/c, their lifetime is 166 microseconds. The rate of neutrinos (number per unit time) passing through the MiniBooNE detector from the Debuncher will decrease with this lifetime.

For reference, the lifetime of an 8 GeV/c momentum muon in the Debuncher is given by:

tau = gamma * tau_zero.

tau_zero = muon lifetime at rest = 2.197 microseconds

gamma = E / m_zero

E**2 = (pc)**2 + (m_zero c**2)**2

p = 8 GeV/c

m_zero = muon rest mass = 0.105658 GeV/c**2.

If one wanted to be more precise, one would not assume 8 GeV/c momentum for the muons, but one would instead use the momentum corresponding to an 8 GeV kinetic energy antiproton, which is 8.89 GeV/c. In this case the lifetime of the muons would be about 185 microseconds.

Nevertheless: The time distribution of neutrinos passing through the MiniBooNE detector from the Debuncher is wider by a factor of order hundreds compared to those coming from the MiniBooNE beam.

<u>Conclusion</u>

If the four assumptions hold, neutrinos created in the Debuncher will not overlap in time in the MiniBooNE detector with neutrinos created in the MiniBooNE beam for up to 11 MiniBooNE pulses.

<u>Caveat</u>

More work on this topic will be required to properly evaluate other situations under certain very credible scenarios. For example, the Main Injector cycle time is very often greater than 2 seconds, and MiniBooNE will always wish to run at 5 Hz. As a specific example, suppose the Main Injector cycle time is 3 seconds and the four assumptions from above still hold. Then MiniBooNE would achieve 5 Hz by having 15 cycles in a row, rather than the 10 shown in Figure 2. In this case the 12^{th} through 15^{th} MiniBooNE pulses would leave the Booster after beam is extracted from the Main Injector. But whether the few hundred microseconds of Debuncher neutrinos overlap with the 1.6 microseconds of MiniBooNE beam neutrinos is not clear from the analysis presented above. But more work can clarify the situation. For now, I just want to publish this note as is and leave some work for later.

Final Note

My thanks in preparing this note go to Bonnie Fleming, Steve Brice, Andrew Green and Peter Kasper.

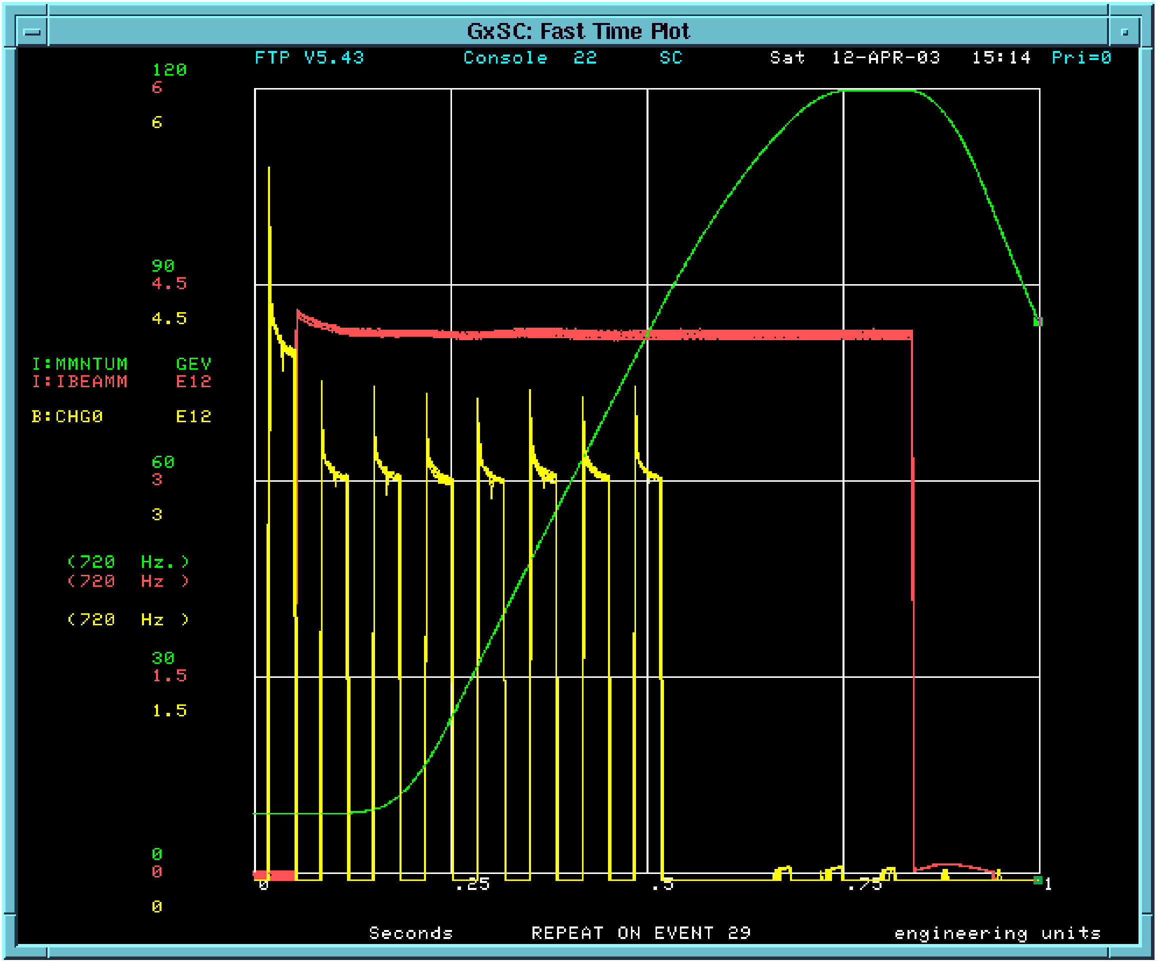

Figure 1. MiniBooNE and Stacking. The Main Injector ramp is shown in green I:MMNTUM; the beam in the Main Injector is shown in red I:IBEAMM; the beam pulses in the Booster are shown in yellow B:CHG0. The single Booster pulse for the Main Injector is followed by seven Booster pulses for MiniBooNE.

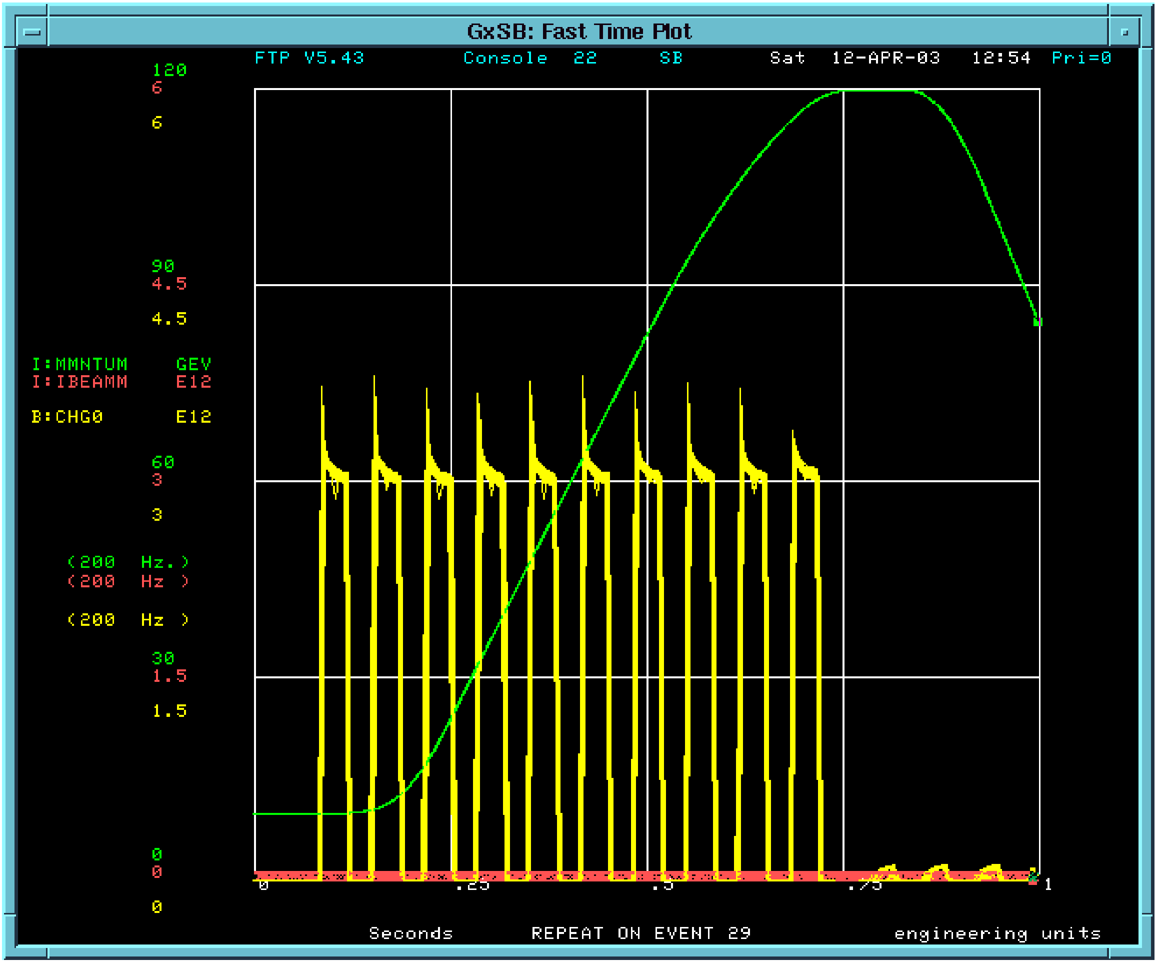

Figure 2. Ten Booster batches for MiniBooNE are shown with the Main Injector ramp.

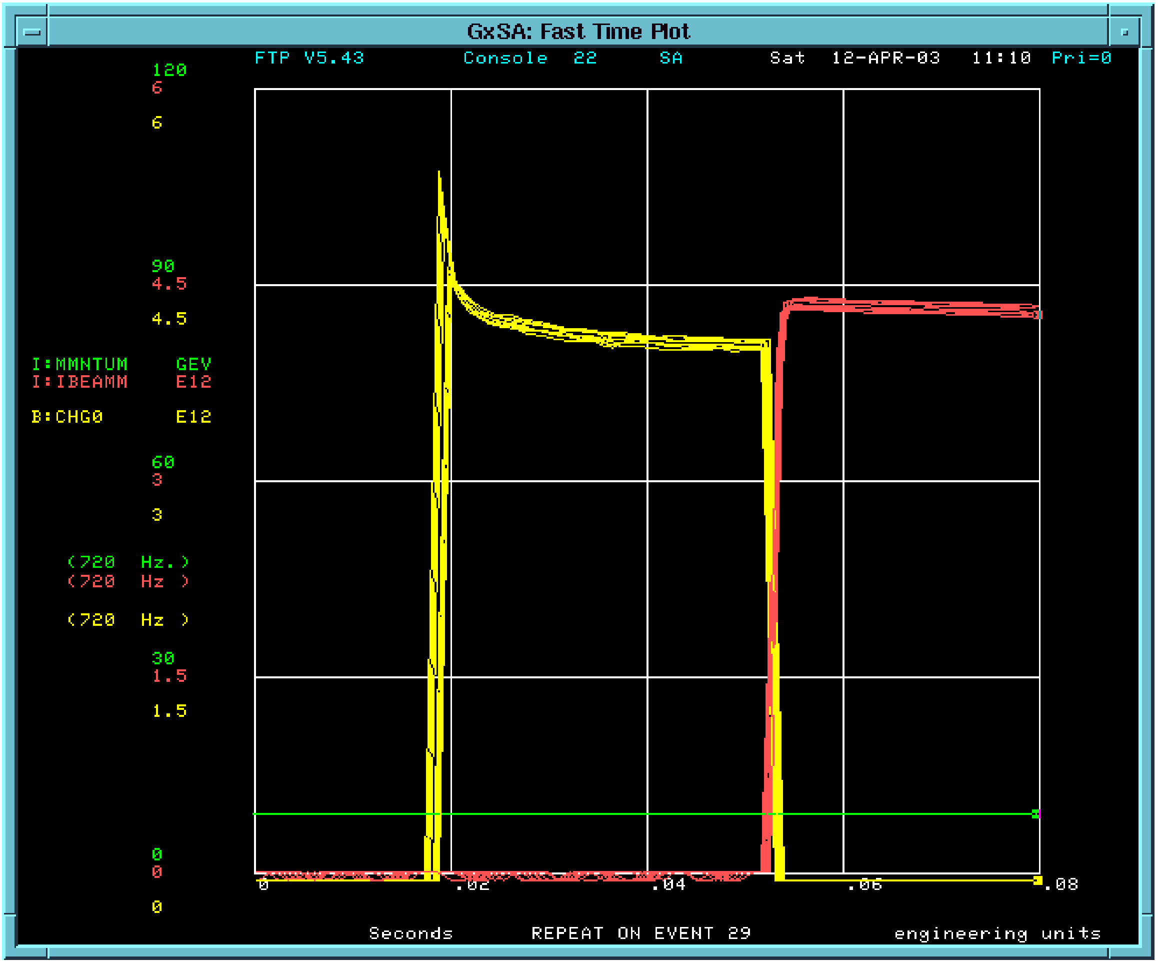

Figure 3a. Expanded scale for injection of a Booster batch into the Main Injector. This figure is used to estimate the time at which beam is injected into the Main Injector. This time is then used to determine when the tenth MiniBooNE beam pulse is extracted from the Booster (see text). (Aside: The calibration on the Booster beam monitor is in error by about 10%.)

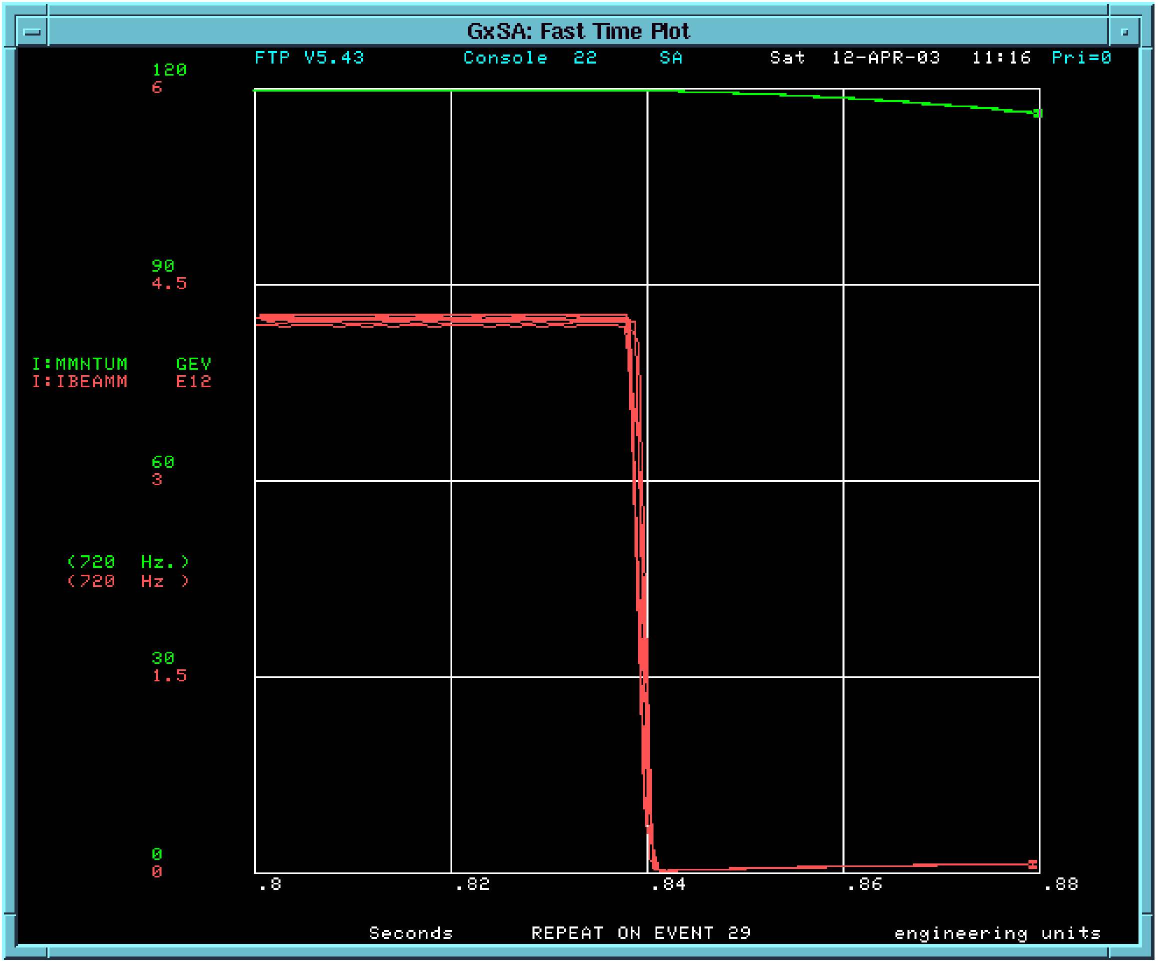

Figure 3b. Expanded scale for extraction of beam from the Main Injector destined for the Antiproton Source.